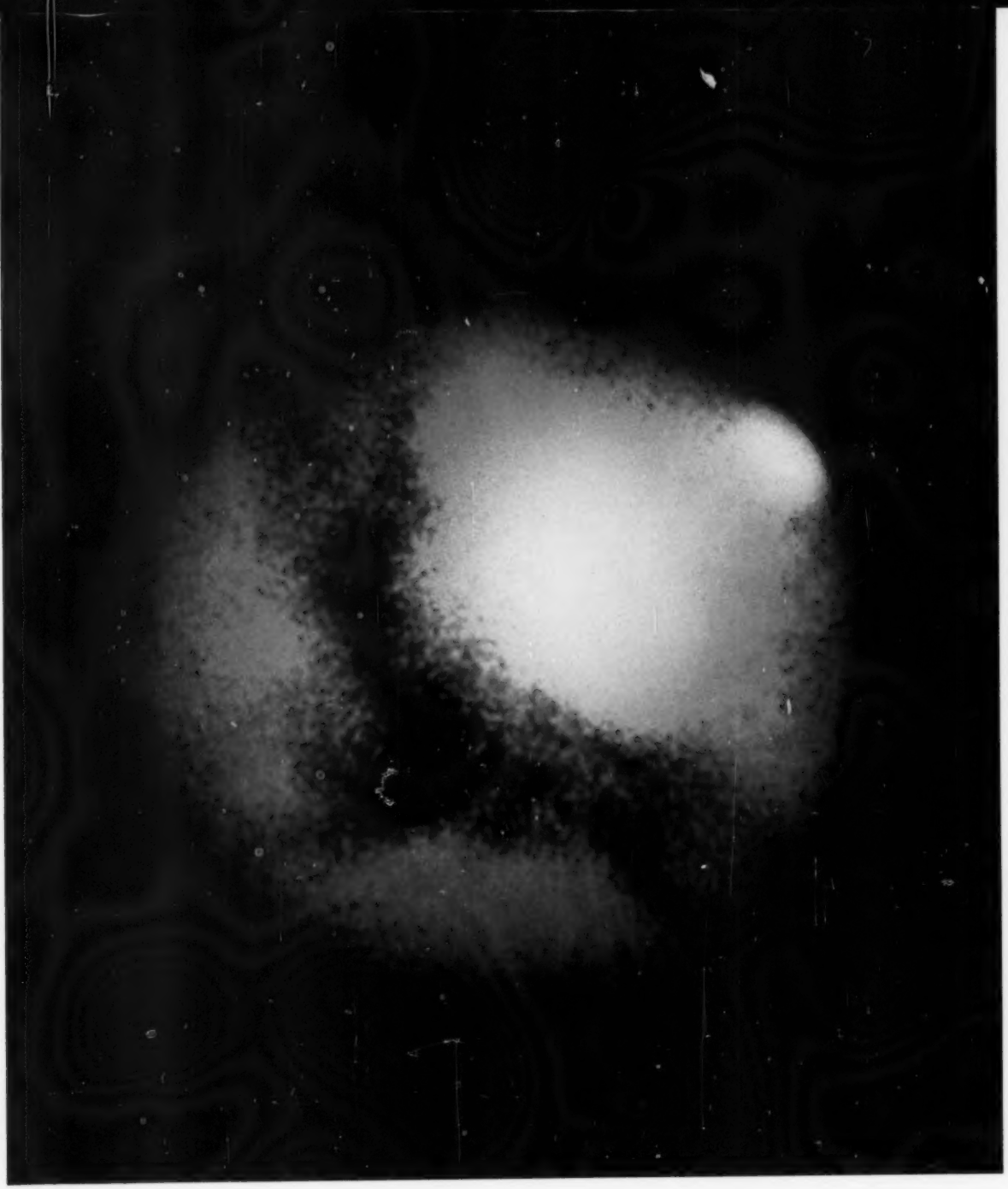

AUTUMN, 1961

Frontier

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in this issue: problems of landing astrovehicles on the moon and terrestrial planets

COMMENT

FRONTIER articles are often reprinted in other magazines having specialized interests. This wide use of material is a good indication that FRONTIER is fulfilling its main purpose—the dissemination of scientific information. It also indicates that FRONTIER offers a great amount of diversity in its articles, both in the variety of subjects presented and in the way they are treated.

In this issue, for example, articles appear in the fields of the life sciences, ceramics, and production management. One article discusses specific problems in space exploration; another comments upon the progress of Japanese research since World War II.

Treatment of material is also diverse. Some articles are closely tied to the achievements of Armour Research Foundation. Others elucidate the state of the art in changing technologies or survey current scientific problems.

These articles are available for reprint, and editors are invited to write for the necessary permission. FRONTIER would also be pleased to hear from its readers about its successes or failures.

WINTER ISSUE

In the Winter issue . . . individual companies combat the costly problem of metal wear through practical testing procedures they have developed over the years. Dr. Robert Read proposes that a more fundamental knowledge of wear is needed. He discusses the approaches now being taken by various research groups to establish a sizable body of scientific knowledge on this subject. And he explores the complexity of problems connected with metal wear study in the absence of a highly developed science.

COVER—Mars, the red planet, easily identified by its white polar cap, changing bands of vegetation, and red haze, will be one of the first planets explored by man.

PHOTO CREDITS: Cover—Yerkes Observatory; Page 5—Ford Motor Company; Page 11—UPI; Page 18—UPI; Page 19—Mount Wilson and Palomar Observatories.

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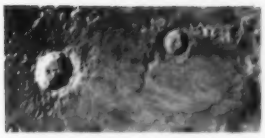

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ASSEMBLY LINE ANALYSIS

The first analytical look at assembly lines has produced methods and techniques to replace the cut-and-fit systems of the preceding fifty years. Result—lower assembly costs

BY MAURICE D. KILBRIDGE AND LEON WESTER

It has been fifty years since Henry Ford invented the modern assembly line, yet mass production industries are still wrestling with the basic problems the system poses. How long should an assembly line be? To what extent should the division of labor be carried? How can the work be divided evenly among the operators? Through the years, these problems have been solved by cut-and-fit techniques. Now at Armour Research Foundation, they are receiving analytical attention.

The first progressive assembly line was started at the Ford Highland Park plant in 1913, and Henry Ford is properly credited with its invention. He combined the principles of the division of labor, the fabrication of interchangeable parts, and the movement of product past fixed work stations into the concept of assembly as a continuous process.

On the progressive assembly line, operators are stationed along the line on which the frame of the product being assembled moves. The total job is broken into elements of work and assigned to various stations on the line. Each operator adds his share of work as the product passes him. The time the product spends at each work station is called the "cycle time."

The assembly line has been used by American industry because it increases productivity and cuts certain costs, such as wages and the expense of training, as the work is divided and de-skilled. But division can be carried too far. Some costs decrease as a division of work proceeds, but others, such as the cost of non-productive work, tend to increase. Beyond an optimum point, which must be ascertained, the total assembly cost turns upward, defeating the purpose of a further division of work.

Many factors join in determining this optimum point. They are economic and technological, and they vary with specific situations. The ARF analytical method takes all of these factors into account when determining the best division of work for a particular assembly line.

Setting up an assembly line for the least-cost system of assembly involves two separate sub-

This typical work station on an automotive assembly line shows multiplicity of tasks performed. Vehicle moves at uniform pace; operators walk alongside or ride line with it. Mixed-model line is shown, with a four-door sedan in position. Next unit may be convertible or two-door sedan, thus varying the tasks to be performed by the operators.

problems, which must be solved sequentially. These are the "cycle time" problem and the "line balancing" problem.

The cycle time problem consists of choosing the optimum extent to which the total assembly should be broken down. The line balancing problem consists of apportioning the work elements among the stations of the line as evenly as possible, taking care to observe the order in which work elements must be performed and to stay within the chosen cycle time at any station.

Optimum cycle time is defined as that which yields the lowest unit cost of assembly. It is found by minimizing the total of two classes of cost factors: intrinsic and extrinsic. Intrinsic factors are those inherent in, and involving only, the man-work relationship. Extrinsic factors are cost elements outside of this relationship, such as availability of space, sales requirements, etc.

A first approximation of the optimum cycle time for a line is derived from the least-cost combination of two intrinsic factors, learning cost and handling-time cost. The cost of learning favors shortening the cycle time, whereas cost of handling generally favors lengthening it. As work is subdivided and de-skilled, the rate at which operators learn their tasks increases sharply. At the same time, learning costs associated with employee turnover and product and model changes decline.

There is a general relationship between task length and learning cost. This relationship has been developed for assembly line work, and a system by which specific cost studies can be made has been worked out at ARF.

Among other things, it has been established that the work pace ultimately obtainable for a given kind of work on an assembly line is a function of the length of task. Ultimate pace is the slowest for very short and very long tasks, and fastest for tasks of intermediate length. When a task is very short, a simple and restricted motion pattern is repeated continuously. This induces cramping and excessive muscle fatigue, inhibiting the worker's ability to maintain a uniformly fast pace. As the task length increases and the motion pattern becomes more diversified, muscle fatigue declines.

When the task is very long, fumbling, forgetting, loss of motor skill, and rechecking time increase, slowing the pace. A task of intermediate length avoids the penalties of both extremes. The operator can develop a touch system, constant rhythm, and

a smooth continuous work pattern, which result in a high level of speed and skill. This relationship between attainable pace and task length has been measured and reduced to a general formula.

Another factor in assembly line learning is "initial learning." This is the time required for a group of workers to reach their ultimate pace when learning a specific new task that belongs to the general class of tasks in which they are experienced. It is the practice effect only, and does not apply to the training of unskilled workers.

The common instruction method is to start a new product at the beginning of the line. As it moves down the line, an instructor trains each operator in turn, until the line is filled and all operators are instructed. The initial learning time is the period of skill acquisition, starting with the end of this new product instruction and ending when the group reaches its ultimate pace. It is a function of task length, and a formula for it has been developed.

The initial learning process is a continuing one, even after the line has reached its ultimate pace, because of employee turnover and transfers. When workers are replaced on the line, the company sustains a learning cost. Either the entire line slows to the pace of the replacement worker, or a special operator works with him. This latter is the customary solution, and the two workers together meet the pace of the line until the new worker is able to keep up alone. The recurring learning cost is, therefore, the wage of the special operator while assisting replacement workers to reach the line pace.

It is necessary to express analytically the time it takes the average replacement worker to overtake the group pace, considering the pace of the group when he starts and the respective individual and group learning curves. Then the average learning cost multiplied by the frequency of replacement for a given period of time yields the recurring learning cost for that period. A general analytical statement of this cost has been derived.

These three components of assembly line learning cost—attainable pace, initial learning, and recurring learning—have been combined into a single analytical formula, by which it is possible to predict the amount of learning cost involved in the use of cycle times of various lengths.

The second of the intrinsic costs to be considered in arriving at the optimum cycle time is the handling-time cost. This non-productive work includes product handling, tool handling, return-to-position time, and station-size allowance.

Produce handling includes putting the product on the line, taking it off, placing it in an assembly fixture, moving it between stations on manual conveyor lines, positioning the product, etc. Tool handling includes picking up and putting aside all tools of production. Return-to-position time is the time required for a worker on a powered conveyor line to return to his original position to start work on the next unit. In standing assembly work, the operator may walk several steps with the product. In seated assembly work, time is spent swinging the upper body from one unit to the next and in searching for the starting point of the next cycle.

The station-size allowance is the additional time required by the operator to move or reach to bring into position the parts he assembles. As the cycle time and the volume of work done at each station increase, so do the number of components used at

Dr. Maurice D. Kilbridge, co-author of this article, addresses a seminar in assembly line balancing. Series of such seminars acquainted hundreds of top management personnel with ARF's method for reducing assembly line costs.

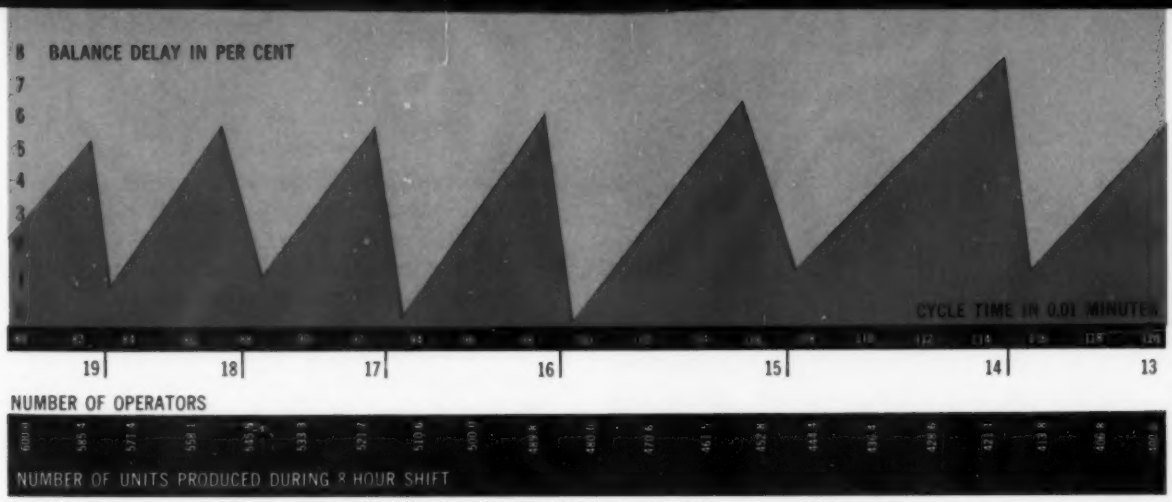


Chart I—In this study of an assembly line operation, curve is drawn for cycle times of 0.8 to 1.2 minutes. Within this range, zero balance results from .99-minute cycle time. Company, however, used .94-minute cycle time, which made 1.25 per cent best balance delay possible. In actual operational experience, balance delay exceeded 5 per cent.

each station. As the storage area required for these components becomes larger, the average distance for reaching and moving components also increases.

By analyzing these four kinds of non-productive time on assembly lines, we have arrived at a general formula which shows the relationship between the division of labor and the amount of non-productive work involved for various classes of work and kinds of assembly lines. This formula plus the learning-cost formula, combined on a least-cost basis, provides us with the first approximation of an optimum cycle time for a given assembly line.

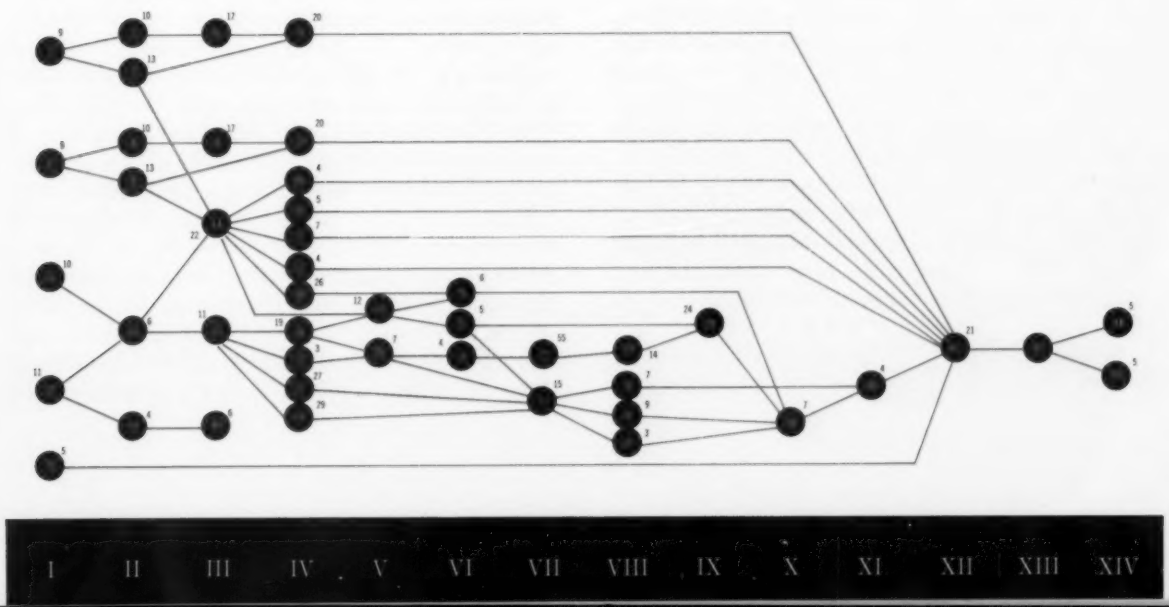
A second approximation of the optimum cycle time may then be found by considering the relevant extrinsic factors, using the first optimum cycle time as a point of departure. This will yield the cycle time best suited to a particular company's situation, and is referred to as the actual optimum cycle time.

The extrinsic cost factors to be considered are such things as availability and cost of space, availability and cost of multiple tooling, personnel available, the wage rate structure for assembly operators, and production volume requirements.

The consideration of the intrinsic and extrinsic factors, which can be reduced to mathematical statements by which the best subdivision of assembly work can be determined, will answer the question, "How long should an assembly line be?"

The second of the sub-problems to be solved for achieving the least-cost system of assembly is the "line balancing" problem. Line balancing, simply

Chart II—This precedence diagram represents an assembly task of 45 work elements. To arrive at best distribution of work, one may move elements from left to right following the lines, or vertically interchange them within columns. Numbers in circles identify work elements. Number outside each circle indicates time required to perform the task.



Kilbridge (left) and Wester (right) demonstrate ARF'S new method of balancing assembly lines to W. B. Scott, vice president of manufacturing for Motorola, Inc., and D. W. Thomas, manager of industrial engineering for Ford Motor Co.

stated, is dividing the work evenly between workers on the line so as to minimize idle time. The idle time which results from an uneven distribution of work is called "balance delay."

Studies show that high balance delay is associated with a wide range of work element times and a high degree of line mechanization. In practice, workers having shorter work assignments will not actually stand idle at the end of each cycle, but usually will work continuously at a slower pace. The effect, in terms of labor cost, however, is the same as if they were idle part of the time.

The degree of imbalance in the line is the ratio between the average idle time at each station and the maximum operation time. Thus, balance delay is the ratio between the total idle time and the total time spent by the product in moving from the beginning to the end of the line. On the average, industry wastes from 5 to 25 per cent of assemblers' time through balance delay.

Balance delay studies have been conducted in many companies using progressive assembly lines. In each case, three kinds of data were gathered: the distribution of time for minimum work elements in assembly; the nature and extent of restrictions on line balancing; and the actual balance delay experienced. It was discovered during these studies that, in general, for a given cycle length, the larger the number of small work elements, the easier line balancing becomes and the lower the balance delay experienced. When comparatively large work elements exist, good balance is more difficult to achieve.

The degree of restriction imposed on the ordering of work elements also influences the degree of balance obtainable. When there are no restrictions on the sequence in which elements may be performed, the line can be more evenly balanced, since there is freedom of choice in the assignment of elements of work within a station and between stations.

At the other extreme, where each element of work must be performed at only one point in a time sequence, there is no freedom in the assignment of work elements, and the problem of balance is more difficult. Most industrial situations are found somewhere between these extremes.

Three types of balancing restrictions have been studied: technological restrictions on the sequencing of the assembly of components; restrictions imposed by fixed facilities or machines on the line; and restrictions of position of the object being assembled with respect to the operator.

Restrictions on the ordering of components are due to the necessity of assembling components in some specified sequence, just as it is necessary to put on one's socks before one's shoes. Such ordering restrictions may affect some or all of the components.

Fixed facilities include machines, testing facilities, and indexing stations that are an integral part of the assembly line and which are immovable stations. At these stations certain elements of work must be performed. Such restrictions decrease the commutability of work elements and make for rigid ordering.

Positional restrictions are commonly known as front-and-back restrictions or top-and-bottom restrictions. They are found mostly in the assembly of larger items. While not present, for example, in the assembly of telephone handsets, they are found in the assembly of console-size television cabinets, gas ranges, and washing machines.

To study the relationship between balance delay and the nature of assembly work, balance delay experience curves were drawn for a variety of assembly situations. These curves indicate that the degree of balance achieved seems to be, among other things, a function of the cycle time chosen. It appears that engineers generally find it easier to achieve a high degree of balance with a longer cycle time than with a shorter cycle time.

Another factor in the degree of balance achieved pertains to the selection of the appropriate cycle

time with respect to the total work content time. If care is taken to choose a cycle time that divides evenly into the total work content time, balance delay can theoretically be eliminated. If a cycle time is arbitrarily chosen, the resulting balance delay time may be high, regardless of the size of the cycle. Carelessness in choosing a cycle time may account for some of the unexplained balance delay experienced in companies studied.

If the chosen cycle time does not divide evenly into the total work content time, the size of the remainder is a measure of the degree of balance delay that will result from the chosen cycle time. This relationship between cycle time and balance delay is known as the balance delay function.

To locate the best cycle times for minimizing balance delay, the balance delay function can be plotted. The graph will generally have the appearance of a zigzag line, reaching the cycle time axis wherever a zero point occurs. Chart I shows a typical balance delay function.

High balance delay is associated with a wide range of element times, a high degree of inflexible line mechanization, and an indiscriminate choice of cycle time. The first two contributing factors are inherent in the nature of the work and the system. The third can be eliminated.

It is estimated that more than half of the balance delay experienced in the companies studied was attributable to the poor selection of cycle time. By using the simple concept explained here, industry should be able to save a considerable part of the time now lost on assembly lines through balance delay.

After the cycle time has been chosen so as to yield the lowest unit cost of assembly and to give the lowest possible balance delay, the assembly line must next be balanced. The problem of line balancing is to apportion the assembly work to the stations as evenly and compactly as possible. This is to be done without exceeding the chosen cycle time at any station and while heeding given restrictions upon ordering of the work elements.

For ARF's system of line balancing, a list of all the elements of work performed on the line, and the time required for each, must first be available. A statement of the restrictions imposed on certain elements as to where they can be done is next prepared, as well as a schematic diagram of the line. Then the analyst makes a precedence diagram.

Chart II is a precedence diagram for a very simple assembly task. The numbers inside the circles identify the work elements; the numbers outside are the time required to perform each element. The arrows indicate the order in which work must be done. Thus, for example, element *1* of duration *9* must precede element *3* of duration *10*. Following prescribed patterns and rules of movement, the analyst transfers elements from right to left in the diagram and interchanges them vertically within the columns to arrive at the best distribution of work. The result is a well-balanced line.

The ARF method of balancing an assembly line requires a certain amount of judgment and analysis of data, and consequently cannot be given over to a computer in its present form. However, work is now being done to convert the general system to a computer routine for ARF's UNIVAC 1105. Once accomplished, the Armour Research Foundation line balancing system will be the most comprehensive and effective system available to industry.

At this time a major effort is being devoted to the model-mix problem. This involves the scheduling and line balancing of assembly work when a variety of models of the same basic product is intermixed on one conveyor line. Existing computer programs for line balancing are of no help since they assume a single-model, straight-line flow.

The ARF method is being used to balance assembly lines in the television, appliance, and automotive industries in a matter of hours. As model-mix research continues and as our efforts to convert the general system to a computer program are intensified, we feel that this new, analytical method for balancing assembly lines will gradually by adopted throughout industry.

Dr. Leon Wester is an operations analyst at ARF, primarily engaged in the statistical analysis of stochastic processes. He also teaches operations research and industrial statistics at Illinois Institute of Technology. Dr. Maurice D. Kilbridge is Professor of Production Management in the Graduate School of Business, University of Chicago, and serves as a consultant to ARF. Kilbridge and Wester have worked together on problems connected with assembly line analysis for several years, and have co-authored several papers on various phases of the subject.

TOXICITY OF OZONE

Ozone has been studied intensely since the end of World War II. Prolonged investigation at ARF has provided a better understanding of the mechanisms of ozone toxicity

BY MAURICE E. KING

Ozone, the triatomic form of oxygen, is familiar to anyone who has walked out of doors soon after an electrical storm. It has a sweet scent that resembles clover or newly mown hay, and is likely to contribute to a feeling of exhilaration in a setting of clean pavements and fresh-washed foliage. Yet it is a poisonous gas far more deadly than hydrogen cyanide or phosgene.

Ozone is also produced through electrical discharges in heavy machinery, expecially transformers and arc welding units. The sweet scent, however, is often absent, replaced by an acrid, unpleasant odor, much like garlic.

Because ozone is commonly used as a laboratory reagent in locating double bonds in compounds, organic chemists know its odor well. If a chemist has had an accident with ozone—that is, if his ozonating equipment has ever sprung a leak and pumped a moderately high concentration of the gas into the laboratory—he knows that ozone has a third odor: strong and highly obnoxious.

Ozone has all these odors, depending upon its concentration in air and upon the presence of nitrogen oxides and other materials in the atmosphere. But the obnoxious odor is the one most characteristic of it, for ozone is a corrosive and toxic agent. A five per cent concentration in air will kill a laboratory animal in 15 minutes. A man will start to experience forced breathing and smarting in the nose and throat after a few minutes' exposure to a concentration of four parts per million of air.

Ozone was first identified as a distinct gas by C. F. Schonbein, in 1845. He observed that paper impregnated with starch-iodine turned blue when exposed to air, the change occurring through oxidation by ozone gas. Because of its long-recognized odor, Schonbein named the gas after the Greek word *ozein*, meaning to smell.

The gas was recognized as a toxic agent as early as 1874, when T. Andrews exposed small animals to high concentrations. A short exposure to ozone rapidly killed them. Since death also occurred when ozone was introduced directly into the trachea, he

knew that death was not caused by injury to the upper respiratory tract. He also observed that extreme emphysema (compression) of the lungs occurred through swelling of the alveoli (the air pockets within the lungs).

Since that time the toxicity of ozone has been periodically studied by many groups, but often with conflicting results. Determining the exact concentration of ozone in air has proved to be tediously difficult, since the researcher has to deal with quantities of the gas that are expressed in fractions of parts per million of air. Besides, ozone is one of the best oxidizing agents known and reacts readily with minute traces of organic matter in the atmosphere—thus greatly complicating definitive measurements.

In recent years a great deal of attention has been given to the study of ozone toxicity at Armour Research Foundation and elsewhere. In the mid-1950's the School of Aviation Medicine, U. S. Air Force, became interested in ozone because of the layer of ozone that encircles the earth at an altitude of about 60,000 feet. High-altitude flights taking people through the layer would pose certain problems. Pressurized cabins use compressed air that is taken into the plane. At these altitudes ozone might be brought into the plane in high enough concentrations to affect the occupants. The School turned to ARF to provide the more accurate information it needed to define and eventually eliminate this hazard.

There has also been much speculation since the middle and late fifties about the feasibility of using liquid ozone as the oxidizer in liquid-fueled rockets, since ozone is a better oxidizer than its sister form, oxygen. If ozone is so utilized, there would be great danger to the men who handled the liquid gas—both from explosion and from leaks. A serious leak at a storage site could conceivably kill a man after a half-minute exposure.

In the forties and fifties ozone was discovered to be a small but important constituent of smog. Although the primary hazard from ozone appears to lie in the products formed by ozone's reaction with other materials, high concentrations of ozone have been measured in heavy attacks of smog (notably in Los Angeles) that would certainly be deleterious to man if the exposure were prolonged. Work is continuing to define more accurately the role ozone plays in smog attacks.

These specific problems have led to a general resurgence of interest in the toxicity of ozone. Since the mid-1950's, clinical studies of small animals have yielded good information on the levels of ozone concentrations that produce toxic effects. Other studies still continue on all aspects of ozone, especially its physical chemistry. But in regards to toxicity, research is now at the point where meaningful hypotheses can be offered about the mechanisms involved in ozone poisoning. Through the examining, testing, and substantiating of such proposals, the theoretical groundwork is being laid so that means of combating the toxic action may someday be discovered.

Acute ozone toxicity—that is, toxicity which produces death in a short period of time—is generally given in terms of the median lethal dose of ozone necessary to kill 50 per cent of a group of animals exposed in a given period of time (commonly written as the LD_{50}). Work at Armour Research Foundation has shown that 12 parts of ozone in one million parts of air (by volume) for three hours is the LD_{50} for mice. The LD_{50} for rats is 13.6 parts per million, and for guinea pigs, 24.8 parts per million.

When an animal is exposed to acute ozone concentrations, he at first goes through a period of high activity, after which he returns to an unexcited state. Soon, he shows difficulty in breathing. Later, if the concentration is high enough, he dies. Upon autopsy two main effects can be observed in his lungs. These are a pulmonary edema (a dropsy-like condition of the tissue) and hyperemia, or hemorrhage. The edematous fluid, filled with air bubbles from the effort to bring in more air, is also found in the trachea. No other organs appear to be affected. The ozone, unlike other poisonous gases such as hydrogen cyanide, does not enter the blood stream by crossing membranes in the lung. Through the introduction of fluid into the lungs, the animal's vital capacity is lowered to the extent that he cannot satisfy his requirement for air. He breathes faster and with more exertion until the decreased vital capacity can no longer sustain him.

Chronic ozone poisoning occurs when the length of exposure or the concentration of ozone is insufficient to cause death but instead produces discomfort, irritation, or impairment of activity. It has been shown that animals experience pulmonary edema at certain levels of chronic ozone poisoning.

In experiments at ARF, effects of chronic ozone exposures were assessed by determining the difference in the weight-gain of controlled animals to that of animals exposed to low ozone concentrations over a period of four weeks. The ozone-treated animals gained less weight, and a relationship between the decrease in weight-gain and the ozone concentration and exposure time was mathematically established.

The type of experiments that determined the presence of edema in laboratory animals are obviously not suited for human experimentation. Accidental exposure, however, has indicated the effects of ozone on men. There have been a number of cases when people engaged in arc welding have experienced a fullness in the chest and have exhibited difficulty in breathing. Sufficient rest in these cases rehabilitated the patients. In cases of accidental exposure and even deliberate exposure under controlled conditions, coughing, smarting in the nose and throat, acute inflammation of the mucous membranes of the nose and throat, throbbing headaches, and partial paralysis of the respiratory organs have been experienced, dependent upon the concentration of ozone and the length of exposure.

The only controlled experiments with men were conducted in 1957 at Armour Research Foundation by personnel of the School of Aviation Medicine. Five men, ranging in age from 19 to 54 years, were exposed repeatedly to different concentrations of ozone and for varying lengths of time. The highest concentration was six parts per million for one hour; the longest exposure was two and a half hours at 1.2 parts per million. Results indicated that edema seems to begin in men at ozone concentrations between four and five parts per million at exposure times of about an hour, as recorded by lung function tests. A definite impairment of the sense of smell was observed at the same concentrations. Individual sensitivity was also shown to differ considerably.

The edema and hyperemia found in the lungs of ozonated animals have long been known as the direct causes of death. What remained to be determined was the chain of chemical mechanisms responsible for these conditions.

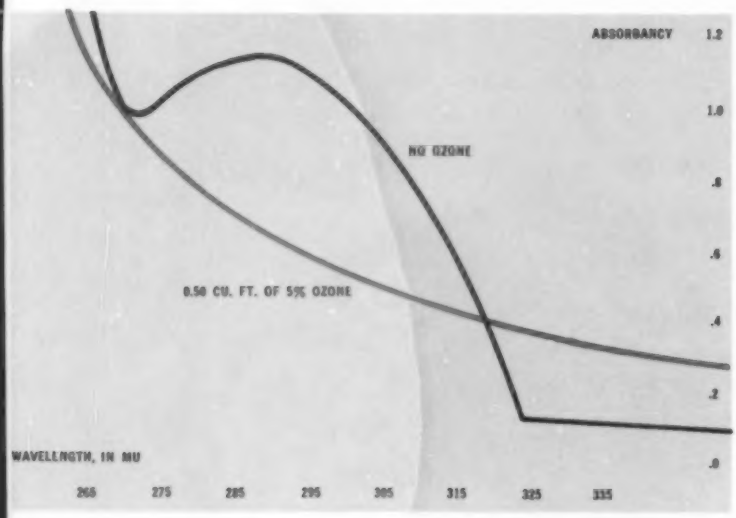
ARF began to look for these mechanisms. Lungs from ozonated rats were examined in order to determine their rate of oxygen uptake and the specific activity of a number of enzymes. These results showed that the enzymatic level in the ozonated

Above photograph illustrates difference between lungs of normal rat (left) and those from a rat killed by an exposure to ozone. Lungs of test animal are almost twice as large due to presence of edematous fluid. Hyperemia and hemorrhage are seen in diffuse coloration and spotting. Photograph below shows test rat being exposed to ozone.

animals was less than that of the unexposed animals. Since these enzymes are protein in nature, the possibility presented itself that the primary reaction of ozone in the respiratory tract is with proteins.

Experiments were then begun to determine whether the reactions observed were specific for these enzymes or common to proteins in general. Since the structure of the protein insulin is known, it was used in a series of model experiments. Solutions of this protein were examined after exposure to ozone to determine if changes had taken place. Many changes were detected, among them a decrease in the ultraviolet absorption around the 280 millimicron region. Protein absorption in this region is due to the presence of the amino acids tyrosine, tryptophane, and phenylalanine. Insulin, however, contains only tyrosine. But when the ozonated solutions were examined after hydrolysis, tyrosine was absent. The ozone had changed it completely.

Further examination of insulin solutions exposed to ozone revealed that the number of phenolic



Graph demonstrates the marked difference between ultraviolet absorption spectra of ozonated and untreated insulin solutions in the 265-315 millimicron range. Absence of a peak at 285 millimicrons for the ozonated solution indicates the absence or modification of tyrosine.

hydroxyl groups decreased and the number of carboxyl groups increased—a clear indication of cleavage of the benzene ring in the tyrosine molecule. Thus there is sufficient evidence that the main reaction of ozone in the respiratory tract is with protein substances.

Upon this evidence the following postulation was made. The chemoreceptors—proteins in the lungs that are responsible for maintaining proper muscle tone of the lungs' bronchioles—probably contain the amino acids tyrosine, tryptophane, and phenylalanine. These amino acids, in turn, would be changed by exposure to ozone, just as the tyrosine residues in insulin were completely transformed upon ozonation. The chemoreceptors would thus be inactivated and their main function— the maintaining of muscle tone in the lungs—would be frustrated. Such inactivation brings about reflex mechanisms leading to the production of adrenaline, which in large quantities has been shown to produce pulmonary edema and hyperemia, such as found in ozonated animals.

Researchers at the U.S. Public Health Service Laboratories in Cincinnati have examined the mechanisms of ozone poisoning from another standpoint. They have been able to show that the reaction of ozone with proteins present in the respiratory tract produces an antigen, which, in turn, produces antibodies in the blood stream of the ozonated animal. The subsequent antigen-antibody reaction causes an allergic response, which in their opinion is responsible for the edema and hyperemia. Both groups recognize that the main reaction of ozone is with protein. The ARF postulation, however, concentrates on the primary reaction—that is, the change of an amino acid in the protein. The other group has focused their attention on secondary reactions—the production of a foreign protein following the action of ozone with the original protein. The ARF research has been more interested in the way the primary reaction occurs. The cleavage of the benzene ring, moreover, could produce an antigen such as the other group describes.

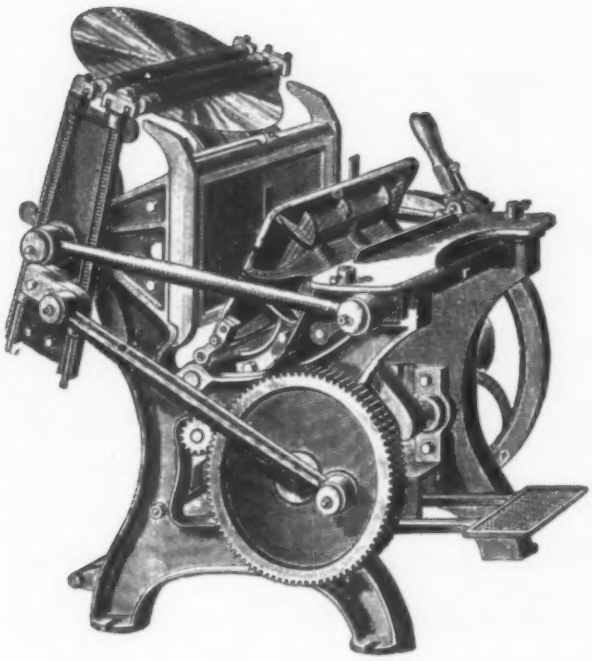
There are several reasons why research into the toxicity of ozone is significant. First, a true understanding of the mechanisms of ozone poisoning is necessary before an antidote can be devised.

Second, a detailed understanding of ozone poisoning may lead to a better understanding of how other noxious gases behave. Hydrogen cyanide has a toxic reaction because it gets into the blood stream and affects the hemoglobin, impairing its ability to carry oxygen. Ozone reacts with protein, modifying certain amino acids present in its structure. A similar chain of mechanisms may be important in other reactions.

Third, the role of chemoreceptors may be more clearly understood. We have known for some time that chemoreceptors exist in various parts of the vascular system and that they help to regulate the carbon dioxide content in the blood. But it has been only recently that their presence on the atmospheric side of the lung has been established. ARF's research, as described above, may promote more interest in these important proteins.

Most important, a better understanding of how ozone reacts with a specific substance benefits all ozone research. Ozone has been studied for over one hundred years, yet many of its properties are not understood. ARF's research, it is hoped, has added to the body of knowledge.

Dr. Maurice E. King is a research biochemist at the Foundation. Since 1955 he has been engaged in ozone research, especially the physiological effects of ozone exposure and the mechanisms responsible for ozone's toxicity.



ARF IN PRINT

Staff members of Armour Research Foundation are frequent contributors to scientific journals. The following list represents a selection of recent articles that cover a variety of subjects.

DEVELOPMENT AND PRELIMINARY TESTING OF A DEVICE FOR ELECTROSTATIC CLASSIFICATION OF SUBMICRON AIRBORNE PARTICLES, G. Langer and J. L. Radnik, *Journal of Applied Physics*, May, 1961.

ELASTIC RESPONSE OF SOIL TO TRACKED VEHICLES, E. T. Selig, K. E. Hofer and N. A. Weil, *First International Conference on the Mechanics of Soil-Vehicle Systems*, June, 1961.

EXPERIMENTAL STUDY OF LARGE-DIAMETER THIN-WALL PRESSURE VESSELS, A. J. Durelli, J. W. Dally and S. Morse, *Experimental Mechanics*, February, 1961.

INTERACTION OF ORGANIC MONOMERS AND WATER WITH FIBERGLASS SURFACES, K. Gutfreund and H. S. Weber, October, 1960.

INTRODUCTION TO COMPUTERS FOR DESIGN, R. B. Wise, B. Mittman, AIEE Winter General Meeting, New York, January 29—February 3, 1961.

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THE SEALING OF SMALL OPENINGS IN SPACE VEHICLE CABINS, J. S. Islinger, Presentation at 1961 Annual Technical meeting, April, 1961.

SOME PROBLEMS INVESTIGATED IN THE STUDY OF MECHANICAL ASPECTS OF REINFORCEMENT, J. S. Islinger and F. K. Halwax, Presentation at 16th Annual Conference, Society of the Plastics Industry, Inc., February, 1961.

SPACE VEHICLE CABIN SEALING—A PRACTICAL APPROACH, J. S. Islinger, Aerospace Forum II, 29th Annual Meeting, Institute of the Aerospace Sciences, January, 1961.

STRESS DISTRIBUTION ON THE BOUNDARY OF A CIRCULAR HOLE IN A LARGE PLATE DURING PASSAGE OF A STRESS PULSE OF SHORT DURATION, W. F. Riley and A. J. Durelli, *Journal Mechanical Engineering Science*, 1961.

A STUDY OF ARTIFICIAL SOILS, E. T. Selig and R. D. Rowe, November, 1960.

FRONTIER would be pleased to mail its readers copies of the above technical articles. However, only a limited number is available. Please address requests to Editor, FRONTIER, Armour Research Foundation, Technology Center, Chicago 16, Illinois.

LUNAR AND PLANETARY LANDINGS

Where and how can spacecraft land safely on the moon or the terrestrial planets? Successful design of these vehicles depends on the accuracy of our answers to these questions

BY NICHOLAS A. WEIL

Travelers from Earth will soon be landing on the moon. Once that satellite has been conquered, their ambitions will turn toward Mars, Venus, Mercury, and then the stars. These prodigious feats are now calmly accepted by the world's populace since the United States and Russia have committed themselves to space exploration.

Landings on the moon will consist of both stationary instrument packages of the Surveyor Series and mobile land-roving instrumented vehicles of the Prospector Series. All of these will be partially controlled by remote command and will telemeter information back to Earth. These unmanned instrument packages are expected to provide sufficient information regarding the lunar surface to allow for safe human landings on the moon with the more advanced versions of the Apollo lunar landing and return vehicle. Even more ambitious plans are being formulated for the Mariner and Voyager deep space probe shots, which will carry instrument packages to the vicinity of Mars and Venus, landing on those planets if possible. The question facing the scientists and engineers who are developing this equipment is: where and in what manner can these space vehicles safely land on these bodies?

In the face of these ambitious plans, it is truly amazing how little is actually known about the surface of the planets—or even of the moon, our closest neighbor. Yet an accurate knowledge of their surfaces, from the point of view of landing conditions, is imperative for the design of spacecraft and for the successful execution of lunar and planetary exploration. The fragmentary information that exists about the moon's surface has given rise to the formulation of many different theories, which in some cases are diametrically opposed. Information on the surfaces of the terrestrial planets is so scarce that no coherent theories have yet been formulated regarding conditions likely to be encountered.

In predicting probable lunar and planetary surface conditions, it should be understood that all one can do is to summarize man's certain knowledge to date, and then set up hypotheses on the most probable conditions likely to exist. The following hypotheses represent the author's views, which have

taken into account existing information and presently accepted theories.

A careful study of available evidence strongly suggests that there is a layer of dust on the open surfaces of the moon, such as the maria, although its depth cannot be more than a few centimeters. In the craters and ring-walled plains, it seems likely that comparatively deep dust beds could have been formed; for here the slopes, exceeding the natural angle of repose for fine particles under lunar environmental conditions, would have been re-exposed to thermal decomposition by repeated dust slides.

Only the lunar highlands and the rims of craters appear to be free of dust, and in these regions bare rock is likely to be encountered. This rock is very slowly being decomposed into dust under thermal cycling due to the alternation of lunar day and night, light erosion, and the impact of meteorites on its hard surfaces.

The dust on the slopes of the lunar craters may increase in thickness to several hundred feet as one descends to lower elevations. This dust is relatively loose, because of the lessened gravitational field of the moon and because of the repulsive force of electrostatic charges. It is conceivable that some cementation of the top surface may have taken place, due to sputtering and the subsequent recondensation of material removed from the dust grains by the bombarding action of solar protons and charged particles. The surface of the dust layer is disposed to an inclination seldom exceeding six degrees, equaling the angle of repose of this material under its environmental conditions. This dust moves downhill, because of reflected sunlight, solar proton bombardment, and lunar gravitation.

It may also be assumed that the dust covering lunar slopes is in a state of rather precarious equilibrium; any substantial disturbance, such as might be created by lunar seismic activity, the impact of large meteors, or the landing of instrument packages, might set off a lunar "dust avalanche."

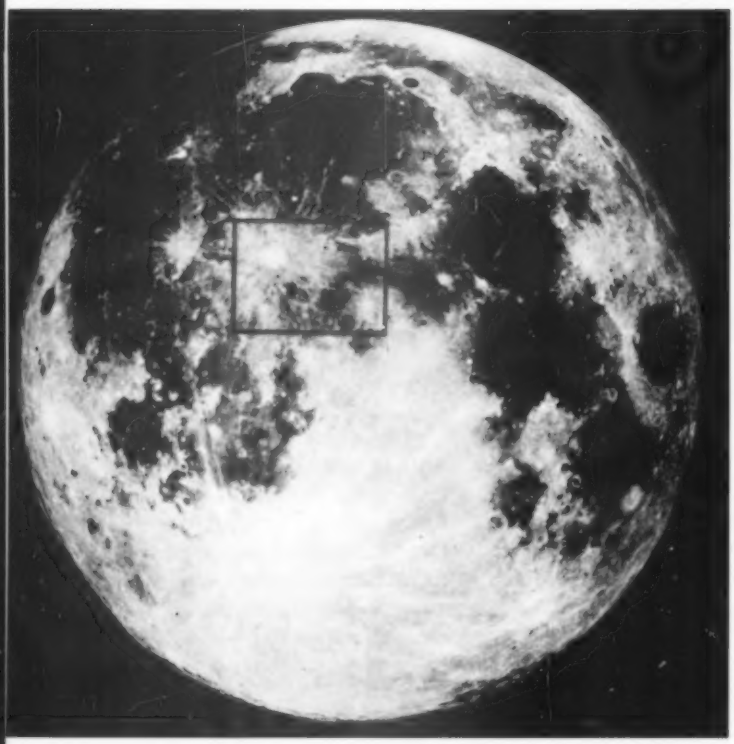
The bottoms of lunar craters are probably filled with dust strata that may range up to several kilometers thick. Under the weight of the overburden, the dust must be more compacted in lower stratifications. The electrostatic charging that the lowermost layers may once have acquired has long since leaked away. It is also possible that the deep layers of lunar dust contain some moisture, originating mostly from impacted meteors, and may be cemented by moisture frozen into ice at the low temperatures prevailing there. Their apparent cohesion must be very high, since friction between the grains is likely to be substantial from the absence of gaseous or liquid lubrication. Hence the bottom layers, cemented or not, are likely to be quite hard.

The density and apparent cohesion drop as one proceeds up through the crater dust beds to the surface, where the same fluffy conditions are expected to hold in the layers constituting the upper few feet as those already described for lunar slopes.

The dust cover of the maria is far thinner. In convex maria, it is probably in the order of centimeters in thickness. Flat or concave maria are overlaid by dust up to several decimeters thick. Beneath this thin mantle of dust lies rock of plutonic origin—basaltic in nature if it is the result of igneous processes or the melting of impacting asteroids, or of an iron-nickel composition if it represents the outpouring of a once molten core.

The particle spectrum distribution of the lunar dust is likely to vary over a broad range, encompassing about five orders of magnitude, from one micron to 10 cm., with a distribution highly skewed

Cross-sectional view of the undisturbed top surface of the moon's maria discloses its assumed stratification.



toward the finer particles. The finer constituents originate from the galactic dust shower and the condensation of meteoric material vaporized upon impact. The medium-sized particles are the result of the thermal defoliation mechanism, while the largest particles are made up of chondrites, achondrites, and metallic meteorites which remained intact upon impacting into the loose dust.

Excepting for the very bottom layers formed during the first few eons of the moon's existence, when crater shaping activity was high, the remainder of the dust (its source being mostly lunar rock and captured galactic dust) is likely to be very close in composition to the chemical constituents forming the moon. This, in turn, is expected to be well represented by chondritic material, at least 40 per cent of which is composed of SiO_2. This may be interspersed with iron-nickel particles coming from iron meteorites.

This hypothesis for the lunar surface would help to explain the telescopic and radio observations regarding surface roughness. On the visible scale, the lunar surface would be rough, since most of the constituent particles of the lunar dust are larger than the wavelength of visible light. On the other hand, lunar gravitation, acting on the electrostatically excited surface dust, would keep the upper layer smooth on the order of the wavelength (10 cm.) of radio observations. Any impacting meteor would be immediately enveloped in the surface dust and sink to lower elevations.

In light of these hypotheses, the possible choices for a lunar landing would be the barren rock of lunar crater rims, the shallow dust layers of the maria, or the deep dust beds of the lunar lowlands. Landings on the lunar slopes may start huge dust avalanches, burying the equipment, and thus be disastrous. Landing on the exposed rock of the lunar highlands entails few unknown conditions. Since these areas constitute an extremely small part of the lunar surface, the guidance problems required to be solved to assure a correct impact location would appear to rule out this alternative.

Most logically, the landing target should be one of the lunar maria. These areas are reasonably smooth and wide open and therefore easily impacted without a control system of the most demanding accuracy. Landings in the maria, if their surface is as envisioned here, would be somewhat softened by dissipating some portion of the landing energy to permit the vehicle to scatter and partially settle into the thin dust layer covering the maria. Exploration of the craters and high topographic features would then be conducted from base camps established in the maria, utilizing tracked land locomotion vehicles.

The floors of craters or mountain-ringed plains appear to offer poor landing targets. If our hypothesis is correct, the landing vehicle may settle into a thick layer of loose dust until it is completely swallowed up.

Even for landings in the maria, one will have to learn what conditions of impact, deceleration, stability, resistance, consolidation, settlement, and locomotion are likely to exist in dust layers in the centimeter-meter thickness range exposed to lunar environments. Some of this work is in progress now, including two research projects at ARF.

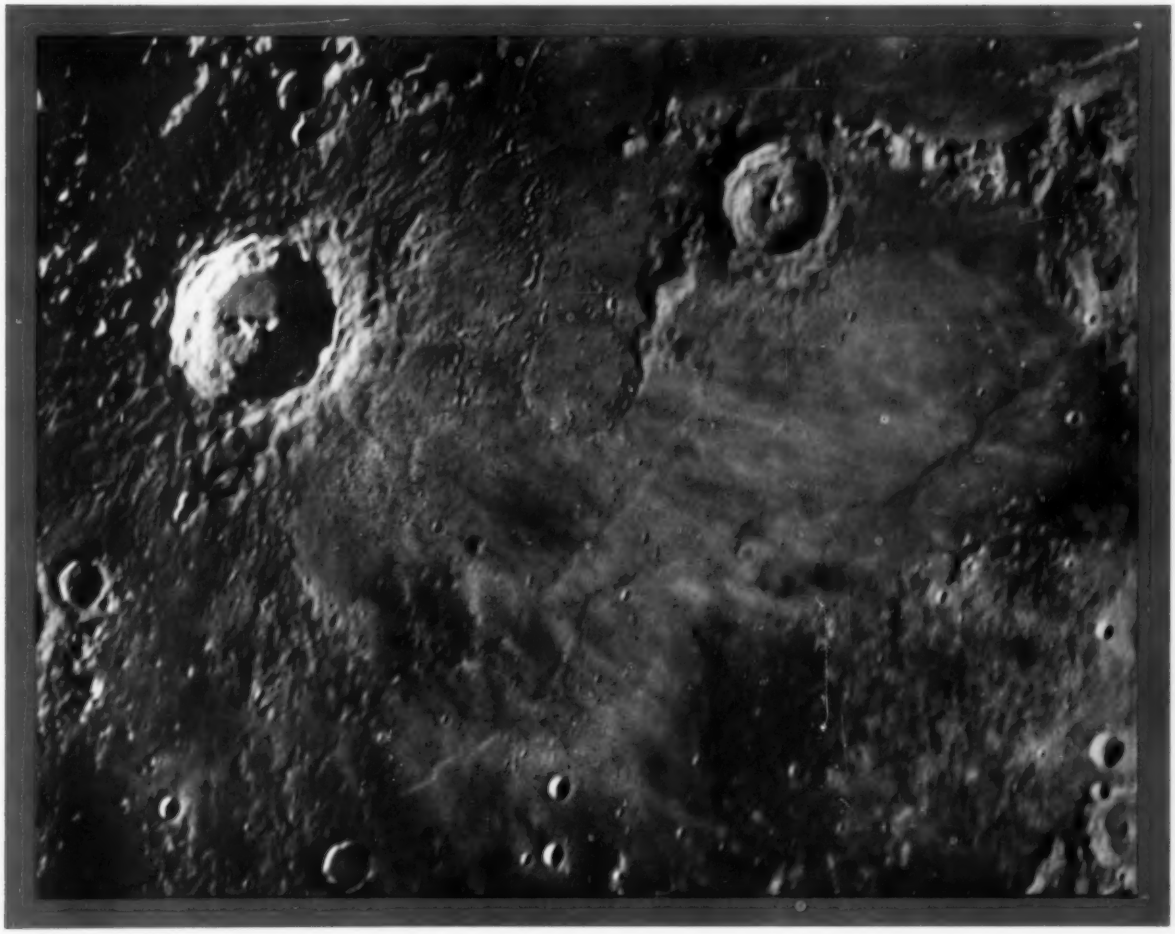
Once the moon has been conquered, man's interest will naturally turn outward into farther space. Here the three planets, Mercury, Venus, and Mars—called terrestrial planets because their density,

composition, and probable interior structure are reasonably similar to those of Earth—will be of first interest. At present, facts regarding the surface conditions on these bodies are extremely meager.

Mercury appears to be comparable in most of its aspects to our moon. It has a period of rotation equal to its period of revolution around the sun (88 sidereal days), and an albedo and density very comparable to lunar values. The low value of the albedo and negative nature of spectroscopic observations indicate that Mercury has virtually no atmosphere. Best current estimates, obtained with polarimetric techniques, indicate the existence of a thin atmosphere, having a pressure of about .0003 that of our own and an unknown composition. The surface temperature on the side permanently facing the sun averages 370° C.; on the unlighted side it is near absolute zero. For lack of a significant atmosphere, there is very little convective heat transfer from one side to the other.

The polarization of reflected light and albedo being the same for Mercury as for the Moon, the surface conditions of these two bodies are also assumed to be similar. Thermal defoliation of surface rocks is unlikely to occur, since surface temperatures on the planet are steady. Because of the low albedo, one may assume the presence of igneous basalt and dark lava, forming a very irregular rough surface. Owing to the surface temperatures on the lighted side, there are likely to be molten pools of zinc and tin, if these elements happen to exist on the planet.

Closer look at the large crater Copernicus (outlined on opposite page) reveals typical lunar surface features. The diameter of the crater exceeds 50 miles; its depth is approximately 12,000 feet. Rough terrain and numerous smaller craters surround it. A mountain-walled plain is located at the bottom of the picture, left of center.



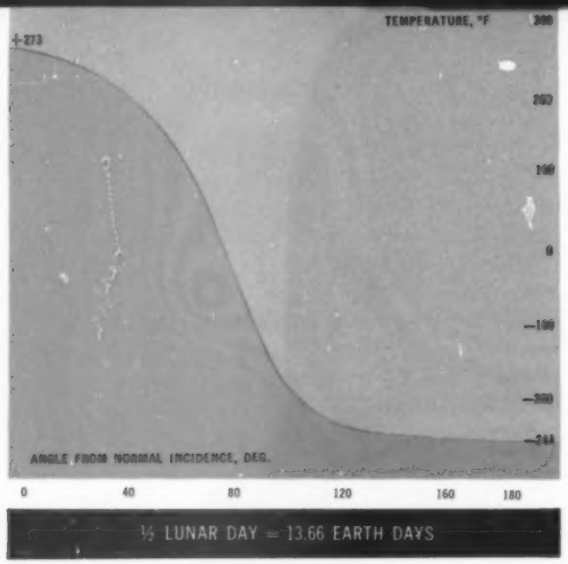


Chart shows great variation in moon's temperature (over 500°F) at subsolar point during one-half of a lunar day.

Because of its location near the sun, the density of particulate cosmic shower descending upon Mercury is likely to be much greater than at the Earth orbit. Therefore, the planet's surface is probably covered with a layer of dust several times as deep as the estimated minimum of two to three cm. on the moon. Mercury's surface, like the moon's, will also be found to show extensive crater formations caused by meteoric impact.

There are no violent storms nor any erosive forces acting on its surface. Mercury is "dead," much like our moon. The problems of landing on Mercury appear to be similar to those of a lunar landing, complicated by a higher temperature. It is possible that more moderate temperatures may exist in the twilight zone between the light and dark sides in which landings could be successfully accomplished.

Venus has physical characteristics most closely approaching those of Earth. However, we know virtually nothing about its surface since all we see is its atmosphere. The temperature at the top of this atmosphere is —38° C. mean. The solid surface temperatures at the bottom of this atmosphere are assumed to be in the range of 200-360° C. The only detectable element in this atmosphere is CO_2; spectroscopic investigations show no trace of water or oxygen. The great albedo of Venus' atmosphere induced investigators to believe that it is laden with globules of liquid or solid materials somewhat over two microns in size, but polarimetric measurements do not confirm the existence of solid dust in the Venusian atmosphere.

The height of the atmosphere of Venus is not known, but the barometric pressure at the surface has been estimated as high as 10 atmospheres. This value appears to be excessive considering that the escape velocity for Venus is about the same as that for Earth. Estimates of a surface pressure of not quite two atmospheres appear to be more reasonable.

Because of their similarity, we can assume that volcanic activity on Venus was comparable to that of Earth and may still be in progress. Some have argued that the surface is covered completely by oceans, but the lack of any detectable water vapor in the atmosphere makes such an assumption unlikely. Photodissociation is certain to have created CO in the Venusian atmosphere, and this would have been retained by the planet because of its comparatively high escape velocity. The atmosphere is also certain to contain CH_4, which would also remain on the planet.

The inferred surface temperatures make it improbable that there is any liquid material on the surface of Venus. Because of shifting streaks, nebulous bands, and changeable bright areas observable in the atmosphere when photographed in ultraviolet light, it is generally assumed that the atmosphere is in a state of violent motion, swirling great clouds of dust to large heights. The accompanying erosive action has probably covered the surface with a deep layer of finely eroded sand.

Venus' surface, then, is in a murky twilight, hot (300° C.) and dry, overlaid by an atmosphere that exerts a pressure of about 1500 mm Hg. The atmosphere is rent by violent storms, generating huge dust clouds, and exerting an enormous erosive action. Because of this, there are likely to be extensive and deep dust beds on Venus, but few surface features breaking the monotony of the terrain. The dust is ground to a particle size on the order of two microns or finer. The violence in the atmosphere—as well as the dust and a terrain that may be shifting constantly, as the sands of a desert during high winds—will be a serious hazard in any landings attempted on Venus.

Mars is the only celestial body, except the moon, whose surface features can be photographed and measured under telescopic observation. Information accumulated to date shows the existence of white polar caps—large areas whose color changes from gray to dark green with seasonal variations; vast

permanent orange expanses; and a network of thin lines sometimes identified as "canals."

Mars has very pronounced seasonal variations, with the seasons about twice as long as those on Earth, during which the surface temperature ranges from −120° to +30° C. At perihelion, the northern hemisphere is in the "winter" season. The dark green areas change to brownish gray at its approach. Based on this, we speculate that some simple form of life—lichens and mosses—is likely to exist on Mars. The reddish-orange areas show little color change with the seasons.

The retreat of the polar caps during summer is not uniform; there are always small patches in the same location that hold out for weeks after the whiteness disappears from the surrounding area. This suggests substantial differences in elevations on the Martian surface, in the form of plateaus having very mild slopes and heights not exceeding 10,000 feet. High mountains, however, are not expected on Mars, since no irregularities have been noted.

The polar caps are almost certainly formed of water in view of the prevailing Martian temperatures (too high for dry ice to form), the reflectivity of the caps (far lower than that corresponding to CO_2), and recent polarimetric measurements.

The true color of Martian soil (exclusive of the maria) is moderately reddish. These areas cover 75 per cent of the Martian surface and are assumed to be barren deserts consisting of granular or powdery form of iron oxide (ilmenite or limenine). The graininess of the surface and the opacity of grains is confirmed by the low albedo of Mars.

Mars is surrounded by a "blue haze" (whose color is actually red by all standards) and therefore definitely has an atmosphere. This atmosphere is known to be some 40 km. high with a surface pressure of 65-85 mm Hg. This is about 10 per cent of the terrestrial sea level value, and corresponds to atmospheric pressures existing at an elevation of 55,000 feet on Earth. Spectroscopic evidence shows only the presence of CO_2 in the Martian atmosphere, with no indications of water vapor, oxygen, methane, nitrogen, or noble gases.

The Martian atmosphere is very likely to contain carbon monoxide, formed by the decomposition of CO_2 under solar radiation. The atomic oxygen so formed escapes. CO, because of its high dissociation energy, will be little affected by photodissociation and will stay in the atmosphere. So will nitrogen. From known data of temperature and pressure, it appears that the atmosphere is made up of 93.8 per cent N_2 and about 2.2 per cent CO_2, the balance consisting of CO, H_2O, and noble gases.

Erosive action has been forceful on the surface of Mars, but the planet has retained some differences in elevation, as evidenced by plateaus and relatively narrow and shallow depressions (the canals). Most of the surface is dry desert land consisting of granulated or powdered iron oxide. A thin layer of vegetation covers about one-quarter of the surface, and a very thin ice cap forms at the poles, the sizes of both of these regions changing with the seasons. The atmosphere is thin, being only one-tenth that of earth, and is in violent motion, generating great dust storms. Because of the filtering action of the atmosphere, objects on the surface would acquire a deep reddish tint.

Of the three terrestrial planets, Mars appears to offer the fewest complications for a landing, particularly since such a landing can be planned to take advantage of the decelerating action of the Martian atmosphere, the rather temperate climatic conditions, and the fact that the surface is expected to contain no gross irregularities.

The information we have been able to gather about the surface conditions of the moon and terrestrial planets is sketchy. Yet, in contrast, Columbus knew far less about his destination than today's astronauts know about theirs. His crew was filled with fear about the sea monsters they might meet. They wondered if they would sail off a flat earth. Precise observation of the moon, Mars, Venus, and Mercury have at least given us a basis in fact upon which reasonable hypotheses can be built. These hypotheses, in turn, are necessary for the proper planning and execution of lunar and planetary exploration.

Dr. Nicholas A. Weil is Director of Mechanics Research at ARF. The material for this article was taken from a paper he delivered at the First International Conference on Soil-Vehicle Mechanics, Turin, Italy, in June, 1961. He has authored numerous technical papers in the fields of stress analysis, material properties, metal forming techniques, dust entrainment conditions, lunar and planetary studies, and pressure distribution in soils.

RESEARCH IN BRIEF

Armour Research Foundation engages in research that encompasses virtually all of the physical sciences and related technologies. A few of its current activities and research projects are briefly summarized in the following paragraphs.

FALLOUT SHELTERS

Armour Research Foundation is now engaged in a research project, sponsored by the Navy, to develop analytical methods and conduct measurements for determining the behavior of nuclear radiation penetration of shelter entranceways and air ventilation ducts.

A six by six foot concrete shelter entranceway, containing one right-angle bend, has been constructed adjacent to the Foundation's research reactor, for simulating a bomb's radiation. The L-shaped entry can be given variable dimensions. To date measurements have been made with neutron and gamma ray radiation. Future experiments will include measurements on entranceways having two right-angle bends and small air ducts to obtain neutron dose distribution information. The Foundation's UNIVAC 1105 computer is being used in this work to facilitate the analytical approach which requires complex integration.

Increased concentration on shelter research is planned by the Foundation in an effort to supply Civil Defense Authorities with necessary shelter design information.

PARTICULATE MATTER IN METEOR TRAINS

The particulate matter formed in meteoric trains entering the earth's atmosphere is currently being investigated at the Foundation. The results open new approaches to the study of chemospheric aerosols.

In 1953, an Australian researcher, E. G. Bowen, proposed that certain peaks in the intensity of rainfall result from the influx of meteoric debris associated with the earth's passage through the orbits of Geminids, Ursids, and Quandrids—swarms of meteors revolving around the sun. As a part of this controversial hypothesis, he suggested that particles of meteoric origin may serve as freezing nuclei in clouds.

ARF researchers later suggested that rain forming or freezing nuclei consist of secondary particulate matter formed in meteoric trains. A research program was then initiated to calculate whether agglomeration of vapor molecules is thermodynamically possible; to calculate the size distribution of the secondary particles; to induce experimentally the formation of particles at conditions corresponding to those of meteoric trains; and to explain the mechanism which transports the secondary particles into the troposphere as a well-defined front.

The Foundation's UNIVAC 1105 computer was used to resolve problems connected with the possible existence of secondary particulate matter. Estimates have shown that its influx from meteoric showers is much greater and of a different size distribution than matter from sporadic meteors. It was also demonstrated that coagulation of secondary particles during a 30-day period will produce particle sizes corresponding to the sizes of freezing nuclei found in snow crystals.

Two other conclusions were reached: that the chemical composition of secondary particles should be relatively uniform because of the mixing which occurs during coagulation; and that the formation of larger particles in the wakes of very bright meteors may help to explain the appearance of noctilucent clouds.

ALGOL TRANSLATOR

Developments in digital computer programming over the past several years have led to the welcome introduction of computer languages compatible with all computer systems. Without a common language, a change of computers at an installation entails the expensive task of rewriting programs to fit the new system's language requirements.

The most significant development in this field has been the formulation, publication, and widespread acceptance of the International Algorithmic Language (referred to as ALGOL). ALGOL translators are now being written or planned for many U.S. and European large-scale computers.

An ALGOL translator for the Foundation's UNIVAC 1105 computer has been under development since early this year. This programming system is now being tested and is soon expected to be in general use by the hundreds of scientists and engineers at ARF. The major contribution to this large effort has been made by Robert W. Floyd, associate mathematician of the Foundation's Computer Applications and Operations Research activity.

In contrast to many compilers and semiautomatic coding programs previously developed, ALGOL has the appearance of classical mathematical notation, but at the same time includes dynamic capabilities which enable efficient machine computation. The result is a programming tool of sufficient versatility to match the most complex machine-language repertoire, but which utilizes a notation that is generally acceptable and easy to read. For example, a statement in ALGOL which can be introduced directly into a computer,

$$X:=(-B+SQRT(B\uparrow 2-4*A*C))/(2*A)$$

is easily discernible as a means of computing one root of the quadratic equation

$$AX^2+BX+C=0$$

$$\text{when } X=(-B+\sqrt{B^2-4AC}\ )/2A.$$

An AGOL program once created need never be reprogrammed until the content itself is rendered obsolete, even though a newer computer might replace an existing one at an

installation. Furthermore, future changes in a program can be accomplished easily with ALGOL, since by nature of its mathematical notation an ALGOL program can be understood by someone not acquainted with the computer on which the program is to be executed.

HEART VOLUME MEASUREMENT

The development of a device that measures the effective volume of the heart, instant by instant, and which is capable of being used under normal surgical conditions could rival in importance the discovery of the stethoscope. ARF scientists believe they have found a way to make such measurements, using only simple laboratory apparatus.

The heart is an irregularly shaped bag, constantly contracting and expanding. An accurate knowledge of its changing volume would greatly aid in the diagnosis of various heart diseases and in the study of heart action. Irregular operation of the heart's valves could be detected, muscular deficiencies indicated, and the hydrodynamics of the circulatory system more thoroughly studied.

According to the ARF plan, high-frequency sound energy is introduced into the interior of the heart through a small quartz crystal, an eighth of an inch in diameter and a few thousandths of an inch thick. The sound energy is periodically interrupted to produce pulses of sound, lasting for a thousandth of a second or less. These pulses scatter at random from the heart's walls, thus effectively covering the entire interior surface within this small time. Since the decay rate of the pulses is determined solely by the instantaneous volume of the heart and not by its shape, a direct reading of the heart's volume can be had.

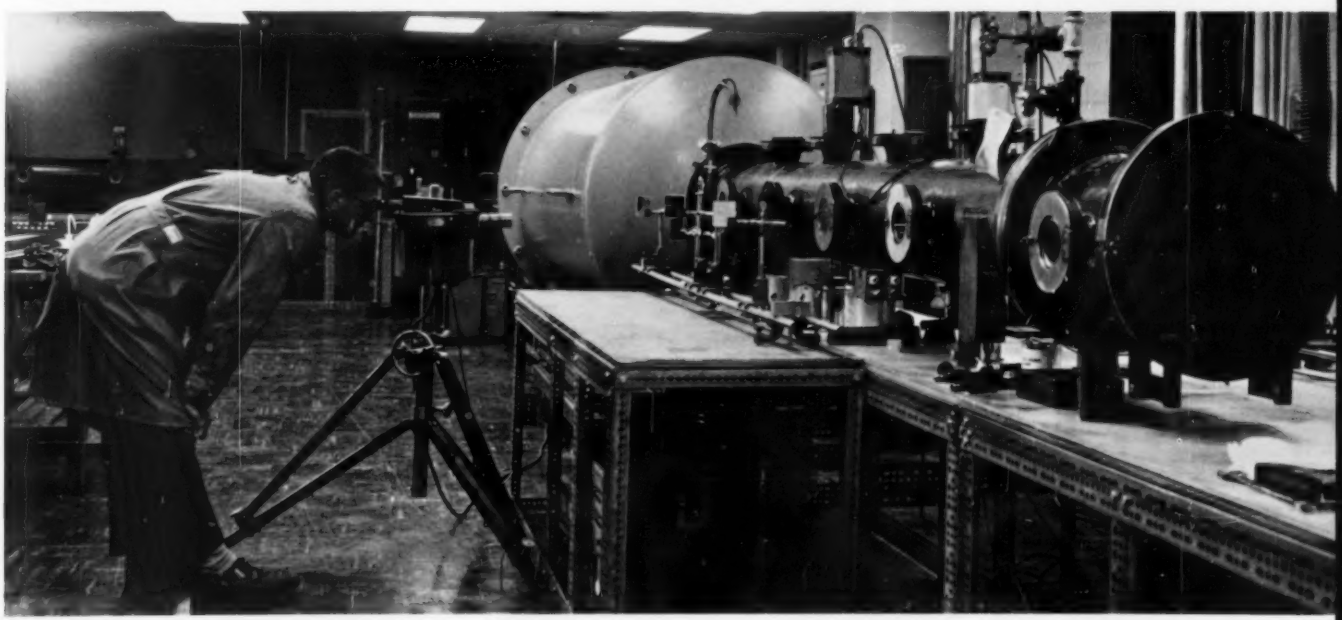
HYPERVELOCITY TEST RANGE

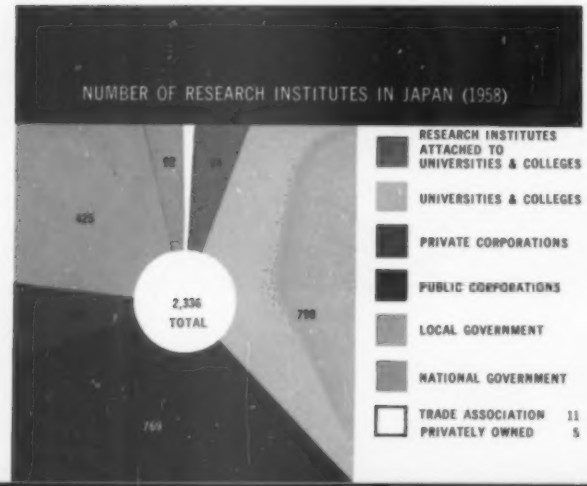
Through the use of a new hypervelocity range, capable of firing test models at 30,000 feet per second, researchers at ARF are collecting basic impact data for advanced vehicle design. Meteorite impacts can be simulated, damage assessed, and protection methods developed. Ablation and heat transfer studies can be made on nose cone shapes and materials. And projectile emission characteristics are being determined for possible use as a basis for detection and guidance schemes.

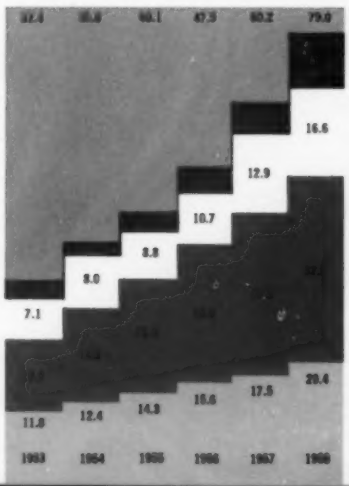
A range of this advanced type, capable of speeds seldom before achieved in hypervelocity research, is suited to a number of research programs, among which is the development and evaluation of possible weapons systems based on hypervelocity principles. In this program, important criteria such as particle size, shape, and velocity for maximum target damage can be readily determined.

Greater velocities will be attained in the future on the new range by the addition of 100,000 or more joules of electric energy to the system. Augmenting the charge of gunpowder, the boosts of electric power will be added to the model as it speeds down the gun barrel, further accelerating it.

An ARF researcher aligns optical device that measures speed of projectiles fired in new hypervelocity range. Facility is now being used for hypervelocity research of all kinds, such as evaluation of weapons systems and critical studies of ablation and heat transfer, impact and cratering, shock wave formation, projectile radiation, and drag effects.







Increase in total money expended for research during the period from 1953 to 1958.

in Billions of Yen

NATIONAL AND PUBLIC RESEARCH FACILITIES

RESEARCH FACILITIES ATTACHED TO COMMERCIAL CORPORATIONS

RESEARCH LABORATORIES ATTACHED TO UNIVERSITIES

RESEARCH FACILITIES ATTACHED TO PUBLIC ORGANIZATIONS

RESEARCH IN JAPAN

Japan will soon become one of the major research nations of the world. Looking for new, diversified products, she is strengthening and enlarging her entire research effort

BY MILTON E. NELSON

No one has to be told that the Japanese are great business competitors. The proliferation of all kinds of low cost industrial goods from Japan—toys, clothes, chinaware, transistor radios—has advertised that fact for years. What is not commonly appreciated is that the Japanese will soon become even greater business competitors, and in areas outside of the light industrial field.

The reason for this new surge is that Japan is about to become one of the major research countries of the world. Its basic and applied research activity has been growing rapidly, though unevenly, since the end of World War II. In a few more years, it should reach a mature and productive stage. New products will then be created, the result not of deliberate imitation but of indigenous talent and design.

The practice of unabashed imitation of foreign products has placed severe limitations on the growth and diversification of Japanese industry. A plethora of toys and chinaware will not help Japan develop into a first-rate industrial power—her prime objective. Only a multiplicity of commodities can do that, with special emphasis on the heavy industrial manufactures and complex electronic equipment that a modern nation needs.

Japan herself, in fact, recognizes the necessity of developing new products and markets or run the risk of a setback in its industrial growth, phenomenal up to now. She is therefore determined to strengthen and expand her ability to perform both basic and applied research.

The Japanese have already proved that their research is effective. Recent accomplishments in electron microscopes, electronic components, new methods of manufacturing pig iron, the production of strong synthetic resins, and other important areas of technology bespeak great competence. Moreover, the world's scientific community has recognized that an increasing number of Japanese research reports are being carried by internationally read scientific journals. Japanese scientists are more in evidence at international technical meetings and are reporting a body of considerable achievement. More patents are being issued to Japanese inventors, and more

American and European companies are licensing products and processes from Japanese firms.

Scientific research in Japan began only a century ago, born of the necessity of bridging the technical gap with the West. Soon after Commodore Perry opened Tokyo Bay to American trade, the Japanese government realized that it was impotent before the military and industrial might of Western nations.

The first research institute was formed twenty years after Perry opened the Japanese islands to Western commerce: an institute of hygiene in 1874. The establishment of an industrial institute and an agriculture institute soon followed in 1876. Other research institutes were founded in the physical sciences. The major research efforts at this time, however, were fostered by the Army and the Navy and consisted mainly of the study and adaption of Western methods of warfare.

The overwhelming success of the Japanese in the Russo-Japanese War showed how adept the Japanese were in learning from the West. At the peace treaty ending World War I (only 65 years after Perry had intruded upon an anachronistic feudal society), Japan was recognized by the world as one of the five major powers.

Portable TV set, recently introduced to American market, is a current Japanese accomplishment in electronics field.

Between the two world wars, other Japanese research institutes were formed. Most prominent were the Research Institute for Iron, Steel, and Other Metals, the Public Works Research Institute, and the Institute of Physical and Chemical Research. Just prior to World War II, research for the national defense received particular emphasis.

Like Germany, Japan began planning for the arduous task of rebuilding its economy after the war. Relieved of the burden of providing for military armaments, the Japanese government directed its attention to the complete rebuilding of industry. In 1947, scientific and academic personnel began pressing for a renewal of research activities. Soon afterward, the Ministry of International Trade and Industry established the Agency for International Science and Technology, placing under its control 12 national industrial research institutes. At the same time, the national research laboratories attached to government bureaus and to universities underwent reorganization to assure more efficient operation. In an effort to stimulate private research, the government, in 1951, began offering subsidies to private companies. This subsidizing led to an increase of research in the private sector.

With the purpose of encouraging science and technology and of boosting the national economy, the Japanese government established the Science and Technics Agency in 1956. Today, it is the planning, promoting, and coordinating medium for all government research organizations. From minuscule amounts in the first years after the war, government expenditures for the advancement of science and technology reached 25 billion Yen ($70 million) in 1960, or 1.61 per cent of the national budget. Expenses for all scientific and technical research have increased rapidly in recent years, from 32 billion Yen in 1953 to 79 billion in 1958.

It would be misleading, however, to represent current Japanese research conditions as ideal. They are not, although they are rapidly improving. Perhaps the most characteristic thing about research in Japan is its unevenness. Some research laboratories compare favorably in accommodations, equipment, and working conditions with laboratories anywhere in the world. Others have antiquated equipment, are poorly housed, and appear to lack good organization. Moreover, the average research institute is relatively small in size when compared to its counterpart in the United States.

As do many growing industrial economies, Japan faces a shortage of scientists and engineers. This shortage has been estimated at 20,000 in 1961. Because industry as a whole will suffer from this lack of trained personnel, the universities are encouraging more students to enter scientific and engineering studies and are contemplating a revision of curricula that will give greater emphasis to programs of scientific research.

The ingrained conservatism in Japanese business practices has been a brake upon the effectiveness of the country's research effort. This conservative outlook is most evident in the paternalism shown company workers. There is very little movement of scientific personnel from one company to another in Japan. When a scientist or engineer joins a company, he does so with the intention of staying with that concern until retirement. The company also presumes that the man it hires is looking for a lifetime position. It expects that his professional growth will be exclusively in its ranks and it expects to reward him accordingly.

The company offers the researcher's family such free services as medical and dental care, private schooling, and recreational facilities. It may even offer him housing at a small fraction of what he would normally have to pay. Although such policies may eventually lead to stagnation and abuse, job security and a strong loyalty to one company have been customary aspects of Japanese business in modern times, just as strong personal loyalty to a clan or estate were traditional elements in feudal Japan.

However, this exclusive attachment to one company may soon come to an end in the face of increased competition for scientific personnel. The major Japanese companies are well aware of this likely trend and are concerned about the subsequent vulnerability of their secrets once the professional working force becomes more mobile.

This paternalism, while protecting each company's secrets, has also had the effect of raising the cost of research, since the company bears the cost of the fringe benefits which make the paternalism possible. At the same time, salaries in Japan are steadily increasing, with many industries last year granting general six per cent increases. In spite of these factors, research costs less in Japan than in the United States by as much as one-fifth. The principal factor is the relatively low salary paid to the Japanese professional man. A Japanese research scientist earns approximately one-tenth of his counterpart in one of the big American laboratories.

The use of contract research and of research consultants has been very limited in Japan, due to the Japanese concern over secrecy. Very little use is made by Japanese business of the nation's universities. And at meetings and symposia that are an integral part of the research community, a reluctance to engage in discussions of mutual concern is noticeable on the part of industrial research personnel. In time, when Japan's research community reaches maturity, it is believed that this pattern will change. Then the participants in a meeting will know what may and what may not be discussed in public, maintaining essential company secrets but contributing to a common body of knowledge.

Even though Japanese research may now be uneven, there is no doubt that its accomplishments in such a short time have been phenomenal. And all indications are that the quality of research done in Japan is steadily improving. Throughout history, the Japanese have proved themselves to be a stubborn and progressive people. Their present concerted effort to raise the quality of research—already noticeable for its achievement—will certainly not fail.

The Japanese are not the only ones who are confident of their success in this endeavor. Major American and European companies, now tied to Japanese interests through licensing agreements, view Japan as an excellent environment for research laboratories of their own. RCA, for instance, is so convinced of the great potential of Japanese research that it has announced plans for constructing a research facility there. More companies, undoubtedly, will soon follow its lead.

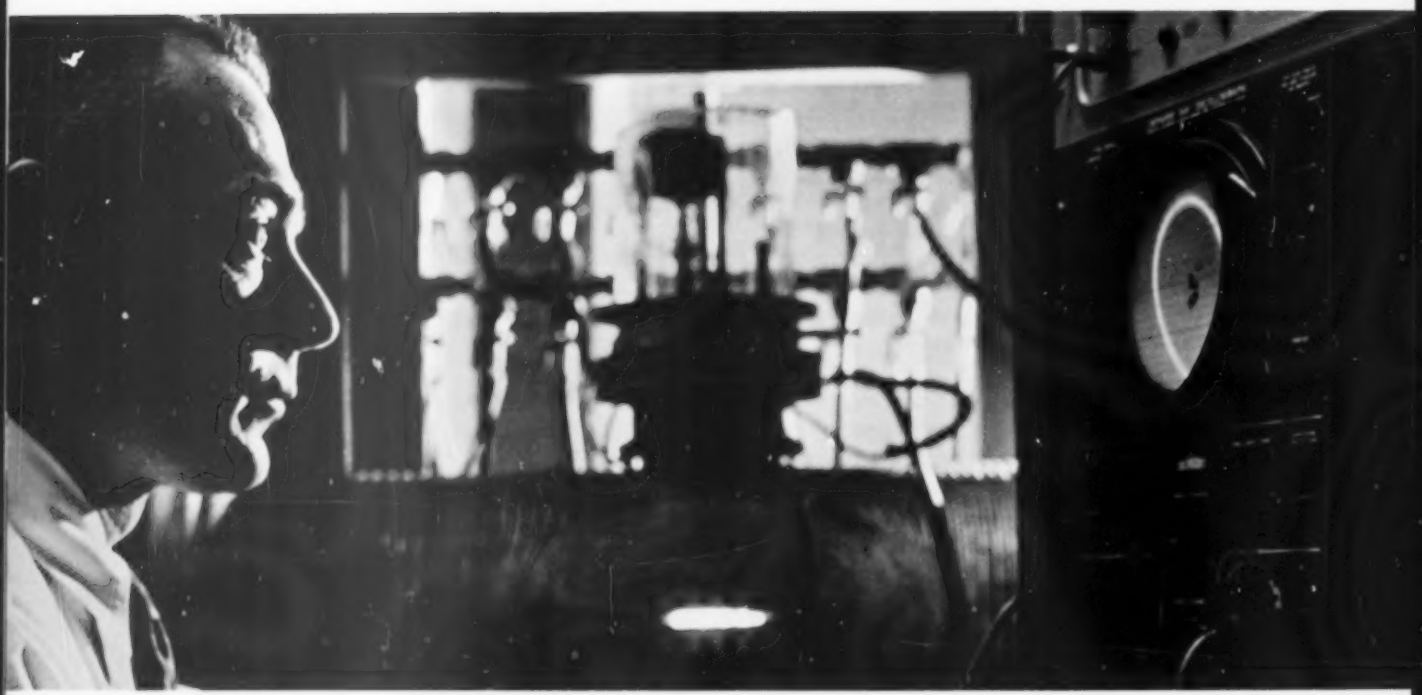
In just a few more years, the fact that Japan is becoming one of the world's great research countries should become evident to all.

Dr. Milton E. Nelson, international research advisor to the Foundation, recently returned from Japan, where he headed an ARF team that reviewed administrative problems of leading industrial research laboratories and conducted management seminars for top-level research executives. He has assisted foreign research organizations in many capacities in such countries as Mexico, El Salvador, Puerto Rico, Burma, Colombia, Venezuela, and Argentina.

GRAPHITE TECHNOLOGY

Through improvements in the technology of its manufacture, graphite is now considered a promising space age material because of its unusual mechanical/thermal characteristics

BY JOHN M. NEFF



Advances in high-speed aircraft, missiles, and nuclear reactor components have surpassed the known capabilities of most traditional materials to resist oxidation and high temperatures. Designers in these exotic fields are now prone to disregard any structural material that has a failure temperature under 1800° C., leaving approximately 122 known materials for consideration. These include 12 refractory metals (such as tungsten and molybdenum), 13 refractory oxides (such as zirconia and alumina), 18 carbides, 12 nitrides, 17 silicides, 19 borides, 22 sulfides, 8 intermetallics, and graphite.

In many ways graphite has the most promise. It is stronger at high temperatures than any other known material; in fact, it gains strength as it gets hot—a unique and important characteristic. Graphite also has superior resistance to thermal cycling; that is, it can withstand the shock of a sudden increase in temperature, as might be experienced in the re-entry of a nosecone, or the continued alternation between extreme heat and cold. Being a strong, hard material, it is easily machinable. Moreover, it is relatively light, having a lower specific gravity than alumina. It is also readily available.

Graphite has proved to be extremely valuable as a moderator in reactors. Furthermore, its high sublimation point, low thermal cross section, and moderator properties suggest its use as a matrix for fissionable fuel. Uranium oxide, the common fuel in reactors, requires a heavy cladding to contain fission products. The density of graphite would make cladding unnecessary. A graphite fuel matrix would also permit more specific energies than present matrices for uranium, permitting the reduction of heavy shielding for the reactor.

As an engineering material, however, commercial polycrystalline graphite has two serious deficiencies. It is usually weak and brittle at room temperatures (as is the "lead" in pencils), and its physical properties vary widely—from batch to batch and from specimen to specimen within a batch. If designers were to make full use of graphite's desirable properties, the technology of producing graphite clearly had to be improved.

ARF ceramists began investigating the technology of graphite in 1957. Through analysis of the fundamental structure and properties of graphite, they sought the reproducible manufacture of strong, dense, non-impregnated, nearly isotropic graphite. In three years of research, after 100 organic compounds had been studied, they achieved their goal by utilizing a new synthetic binder for making molded graphite, reducing the time required to produce strong, dense graphite from several days to just two hours.

Graphite is a mineral specie of the element carbon, crystallized in the rhombohedral system. It occurs in nature in such crystalline rocks as gneiss, schist, and (occasionally) granite. Ceylon, Siberia, and Mexico yield large amounts of the natural mineral. The name itself is from the Greek *grapheiv* meaning "to write," and was first used by A. G. Werner in 1789. Earlier names were *plumbago* (the Greek word for lead) and *blacklead*, both of which gave rise to a still existing confusion of terms. Graphite contains no lead, even though we refer to our most valuable writing instrument as "lead" pencils.

In 1896 E. G. Acheson patented a process for making artificial graphite by passing a high amperage electric current through carbon, and in 1899 the International Acheson Graphite Company was formed, signaling the start of a now very large industry. Even at the end of World War II, commercial graphite was still made in essentially the same manner as it was at the turn of the century.

Commonly, graphite is made from three principal materials: coke, which is the aggregate or skeleton of the mix; pyrocarbon, which serves as a filler and to some degree as a plasticizer; and the binder, usually coal tar pitch or thermoplastic bitumens—all of which interact with each other during processing. This complex situation immediately suggested that the practical approach of the ceramist, rather than the more complicated, theoretical approach of the chemist or metallurgist, should be taken, since even common pottery is composed of silica as an aggregate, clay as a filler and plasticizer, and feldspar as a binder. From a statistical standpoint, multicrystalline graphite has more than 20 degrees of freedom (that is, 20 variables affect the composition of the end product), and most of them are interdependent. It was estimated that more than a thousand man-years would be required to establish the optimum characteristics of a single property, and the whole procedure would have to be repeated if a second property were altered. ARF researchers feel that it was the adoption of the ceramic philosophy at the outset which enabled them to achieve several important goals in a relatively short time.

COMPARATIVE PROPERTIES OF GRAPHITES
(WITH THE GRAIN)

	BULK DENSITY G./CC	GRAPHITE DENSITY G./CC	FLEXURAL STRENGTH PSI
ROOM TEMPERATURE			
COMMERCIAL GRAPHITE	1.70	1.70	3,000
ARF GRAPHITE (NO UC_2)	2.05	2.05	5,520
ARF GRAPHITE, 10 W/O UC_2	2.23	2.04	6,850
ARF GRAPHITE, 30 W/O UC_2	2.78	2.02	11,800
3500° F			
COMMERCIAL GRAPHITE	1.70	1.70	5,000
ARF GRAPHITE, 30 W/O UC_2	2.78	2.02	13,500

Above Table shows the improvements of ARF graphite over commercial graphite in bulk density and flexural strength.

Since most high strength-to-density ratio ceramic bodies are made from fine-grained raw materials, it was decided to concentrate on fine-grained graphite bodies, using commercial cokes, 90 per cent of which pass through a 200-mesh screen, Thermax (a pyrocarbon), and a coal tar pitch binder. Not unexpectedly, these dense, molded bodies cracked and bloated as they were heated, even on a long, seven-day cycle, due to the very low porosity which retarded escape of water vapor and other volatiles from the green mix (that is, the mix of raw materials before they have been heat processed).

The production of commercial molded graphite has traditionally consumed several days because the mix is heated at the same rate throughout the entire heating cycle. ARF ceramists reasoned that the heating of graphite bodies might be accelerated, just as the heating of common ceramic materials, such as building brick, is hastened. Brick has certain critical points in its thermal treatment, at which a rapid temperature rise must be avoided to shun chemical deterioration. But between these points, rapid heating can be applied with no bad effects. The thermal treatment of brick, therefore, constitutes a series of rapid heatings followed by reductions in the heating rate. By differential thermal analysis and continuous thermogravimetric determinations, several such critical temperature ranges were discovered for graphite. By slowing the heating rate in these ranges and accelerating it once they were passed, ARF ceramists produced fairly sound carbonized specimens, which yielded promising graphite specimens after the high-heat processing phase.

Out of 100 compounds that seemed likely candidates for binders, the field was narrowed to two: a thermoplastic coal tar pitch and a family of thermosetting prepolymerized furfuryl alcohol resins.

The next stage of the study consisted of making accurate physical property measurements from room temperature to 5000° F. For this work, a specially designed carbon resistor furnace was built, in which such properties as dynamic and static moduli and coefficients of thermal expansion were accurately and reversibly measured, as well as ultimate and tensile strengths.

Measuring the tensile strength of a brittle material at elevated temperatures has, in the past, offered many problems of temperature gradients, misalignment, complicated grips, and erratic data. In the course of an ARF-sponsored project, a little known theory for a brittle ring tensile test, first proposed by Max M. Frocht in his book *Strength of Materials*, was found to be the solution to the problem of determining the tensile strength of graphite at very high temperatures.

Briefly, the method consists of making an annulus, or ring, of the material under examination, locating it in the hot zone of the furnace, applying an increasing load at the top of the ring, and exerting a force necessary to cause failure. The force necessary to cause fracture of the ring is then incorporated into the formula proposed by Frocht, and by this means the tensile strength is computed. This method has proved to be 90 per cent reliable, as compared to the 40 per cent reliability achieved by usual methods.

By the time the program entered its third year, all binders except the furfuryl alcohol resins had been eliminated as possible components of very dense homogeneous, nearly isotropic, graphite. But even these resins released enough volatiles to disrupt the mechanical structure of the graphitized speci-

John M. Neff is Assistant Director of the ARF Metals and Ceramics Research Division. A veteran of over 30 years in ceramics engineering, he has been among the pioneers in the fields of ceramic coatings and ceramic construction materials. His interest in graphite dates back to early experience in non-ferrous foundry activities and precision casting work.

mens. A breakthrough was finally achieved through the use of a highly resinified prepolymerized furfuryl alcohol made by a process patented by a member of ARF's chemistry research division. The liquid contains practically no unreacted alcohols and volatiles, and can be made with a wide range of viscosities—a factor which contributes to the adaptability of green mixes to the various forming processes, such as molding or extrusion.

It was now possible to consistently make graphite having a density of 1.8 grams per cubic centimeter and an ultimate strength of 10,000 psi at 4000° F. in a matter of a few hours, compared to high quality commercial graphite which has a density of 1.6 grams per cubic centimeter and an ultimate strength of 6000 psi at 3000° F. and which requires days for its manufacture.

The incorporation of nuclear fuel into a matrix of this graphite became the next objective. As was explained earlier, the use of a suitable graphite matrix for fissionable fuel in reactors would eliminate cladding and reduce the amount of bulky shielding. Oxide additions were found to be unacceptable, so major attention was focused on carbides. The monocarbide of uranium, UC, reacted violently with the polymer binder during molding to form the dioxide UO_2. This problem was overcome by using the high density UC_2, protected by a dense coating of pyrolytic carbon. Surprisingly, incorporation of the fuel did not impair the physical properties of the ARF-developed graphite.

Further improvements in the ARF graphite made it possible to produce fueled graphite elements with vastly superior properties in as little time as two hours. (See adjoining Table.)

ARF's intense work with graphite over the last several years has indicated that this complicated material is a worthwhile subject for continued research. Improvements in strengths, even faster manufacturing processes, and a better understanding of structure and stress conditions are a few of the many important aspects of graphite technology which would benefit from further investigation.

Graphite will continue to be an important material because of its inherent characteristics. With the advent of mobile reactor units, fueled graphite technology—promising lighter weight and more specific energies—will be increasingly important. Similarly, designers of high-speed aircraft and spacecraft will turn to graphite for its unusual thermal/mechanical properties. Whatever graphite's uses—in exotic applications or in such common uses as electrical contacts, motor brushes, and metal melting crucibles—superior grades of graphite will continue to be in great demand.

This custom-built, carbon resistor furnace was used for determining the engineering properties of ARF-prepared carbon specimens. Here, the observer notes the physical condition and position of a specimen under full heat.

Armour Research Foundation is an independent research organization which engages in research, development, and experimental engineering for sponsors in government and industry. Its facilities and staff are available on a contractual basis. The scope of its work encompasses virtually all of the physical sciences and related technologies.

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